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TECHNICAL REPORT ECOM 01605-F

DEVELOPMENT OF GENERATOR DIRECT CURRENT G-63 ( )/G (HAND CRANKED)

CONTRACT DA28-043-AMC-01605(E)

By

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March, 1967

Prepared for:

United States Army Electronics Command
Fort Monmouth
New Jersey

Prepared by:

Varo Inc Electrokinetics Division
Santa Barbara
California

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TECHNICAL REPORT ECOM 01605-F

DEVELOPMENT OF GENERATOR
DIRECT CURRENT G-63 ( )/G
(HAND CRANKED)

FINAL REPORT
8 JULY 1965 to 15 NOVEMBER 1966
REPORT NO. 2

CONTRACT NO. DA28-043-AMC-01605(E)

POWER SOURCES DIVISION
DEPARTMENT OF THE ARMY TASK NO. 1E6 40306 D 488-07

Prepared for:

U.S. Army Electronics Command
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ABSTRACT

The Generator, Direct Current, G-63 ( )/G design developed under this Contract encompasses the requirements of ECOM Technical Requirement SCL 7828.

Major component or subassembly areas involved with unit development may be classified as: Alternator and associated circuitry, mechanical drive, housing, and base assembly.

Electrical subsystem development included alternator optimization, rectifier selection, and design of protection and electrical output monitoring circuitry.

Mechanical drive development involved matching the harmonic drive to alternator requirements and additional testing required to isolate and rectify problems of low drive efficiency and high acoustic noise levels generated.

The housing was developed for minimum size and weight for containment of the alternator-drive subassembly and maximum acoustic noise suppression.

The mounting base assembly developed, includes consideration for universal functioning and prime factors of weight, strength, and attachment.

Techniques were considered and implemented throughout the project to promote economical use of parts and fabrication processes. Use of standard parts and components where possible and joining major subassemblies such as housing and base components with the dip brazing process have been incorporated toward an economy which may become even more significant in mass production considerations.

Overall unit considerations resulted in an effort to integrate individual subsystem attributes into an economical unit incorporating factors contributing to operator efficiency for total operation and observation as encountered under field conditions.

Subsequent operational tests have verified general conformance. Areas of deficiency, all a function of the mechanical drive, include overall efficiency, weight as a function of noise suppression required, and marginal satisfaction of noise requirement. Recent drive component developments and additional recommendations by the drive manufacturer indicate that the noise and weight problems may be resolved and efficiency increased slightly. Post qualification analysis indicates that possible improvements may be merited in the areas of housing, electronics packaging, and internal component mounting to contribute to a more economical, lighter weight design.

FOREWARD

The development of Generator, Direct Current, G-63 ( )/G (Hand Cranked) was performed for the U. S. Army Electronics Command, Fort Monmouth, New Jersey, as Task Number 1E6 40306 D 488-07, under Contract Number DA28-043-AMC-01605(E).

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FINAL REPORT

1. DESCRIPTION

The development of Generator, Direct Current, G-63 ( )/G has resulted in an optimum, portable, light-weight, 30-watt generator unit (Figure 1). This unit is capable of charging a 10-cell, 12-volt, nickel-cadmium battery by hand cranking input with nominal effort within the limits of operator endurance. It encompasses maximum utilization of factors contributing to operating efficiency.

Basic design criteria were established predominantly by ECOM Technical Requirement SCL 7828, supplemented by information gained through customer liaison and investigations performed in support of the design proposal. The objective in achieving the optimum design was to satisfy the criteria established by defined and undefined design and operational requirements.

2. DESIGN PROCEDURE

2.1 Initiation

Specification requirements and additional information inherently provided the guidelines leading to sequential component development. Initial work resulted in an experimental alternator and accompanying rectifier unit which approached the specific output requirements of providing 2-amperes current with 15 volts across a load

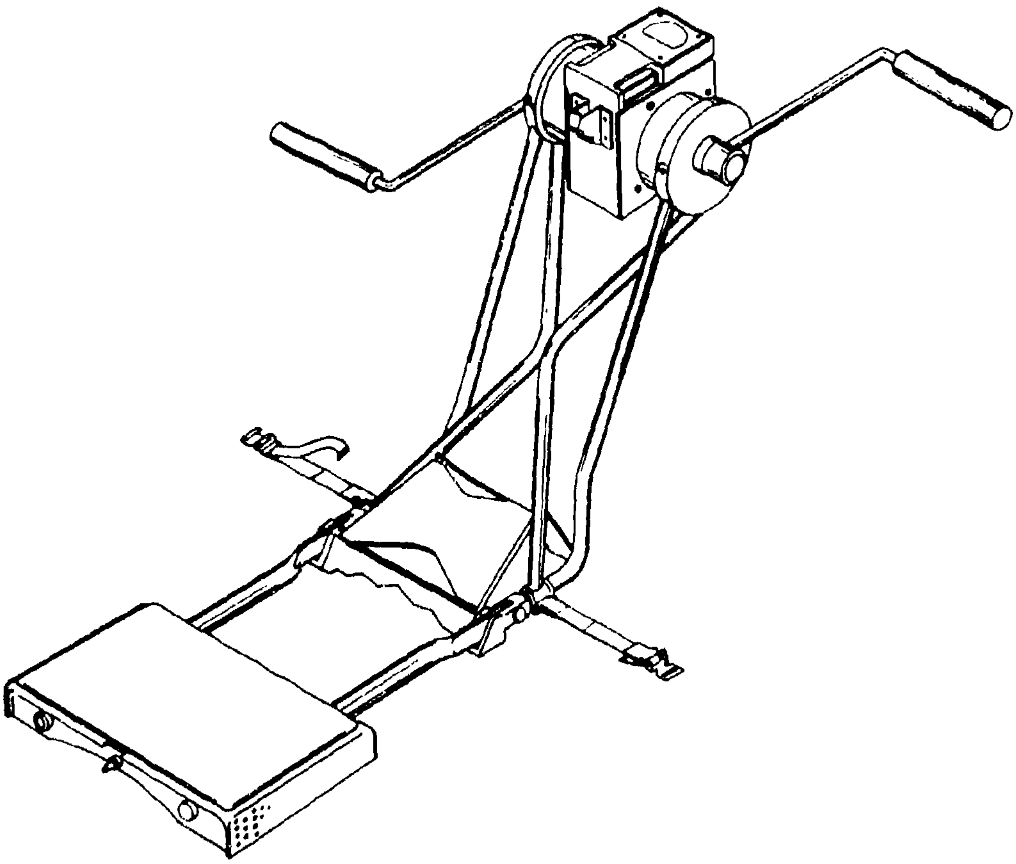


Figure 1

G-63 Generator Unit

simulating the required half discharged battery. Having determined from this the nominal alternator input requirements and space envelope, the size of a required, specified harmonic drive unit (manufactured by United Shoe Machinery), was established. Concurrent with alternator optimization and drive selection, the initial related components, housing, hardware and circuitry layouts were completed and parts acquisition initiated for the experimental model.

2.2 Experimental Model

The experimental generator unit consisted of a 3-phase alternator excited by a 4800 RPM, 4-pole, permanent magnet rotor driven by the output of a size 20, 80-to-1 ratio harmonic drive used as a speed increaser. For maximum utilization of space, the flex spline is stationary with driven circular spline and encloses the alternator unit to form a compact subassembly. The wave generator output is coupled to the alternator rotor by a tubular counter shaft which rotates about the main drive shaft. The main drive shaft transmits cranking power by utilizing a crank-handle assembly attached to each end of the drive shaft to drive the circular spline. This alternator-drive subassembly provides maximum utilization of components with a minimum space envelope. Modification of the flex spline to the length required to contain the alternator was performed in-house from on-hand components due to the long lead time required to receive modified components from the

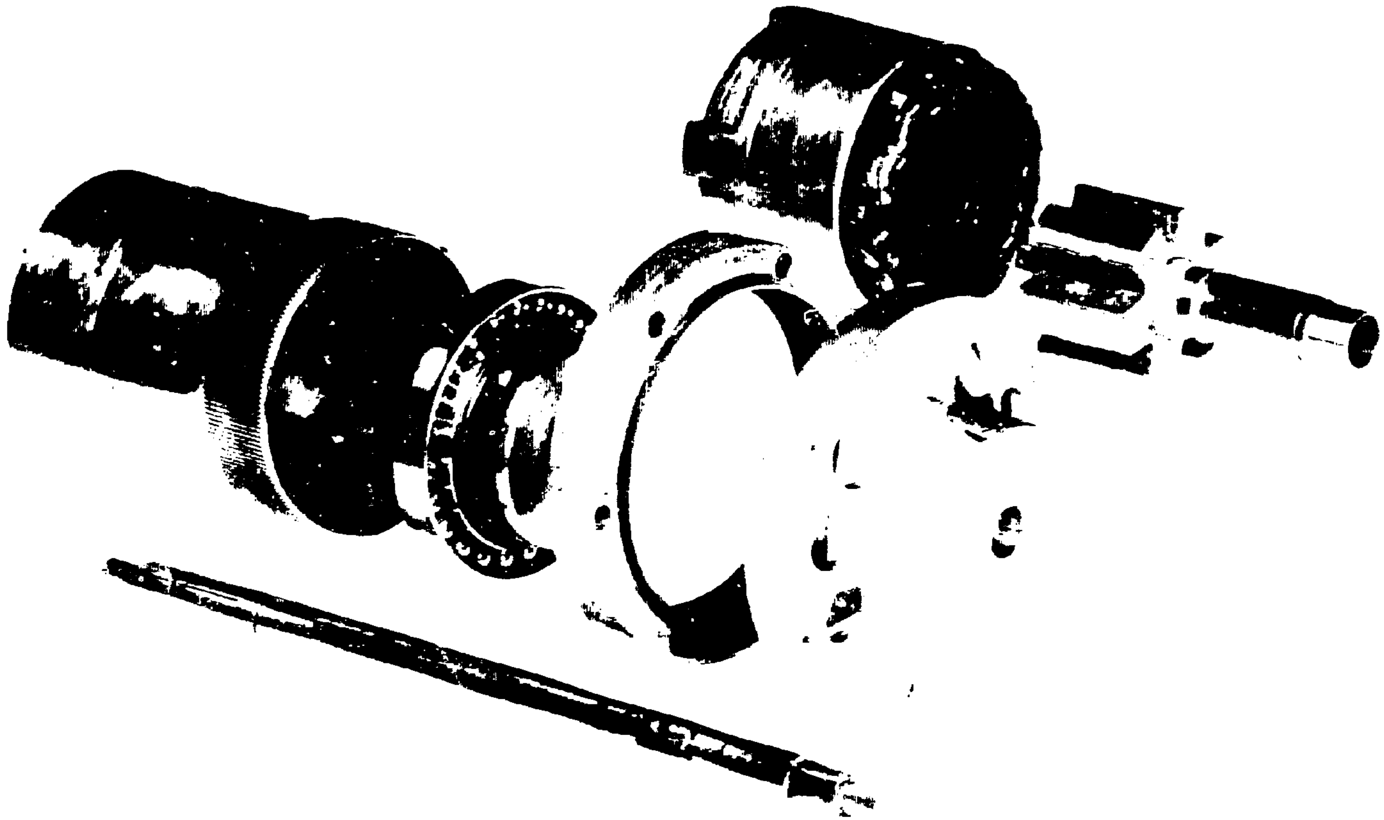


FIGURE 2

ALTERNATOR AND HARMONIC
DRIVE COMPONENTS

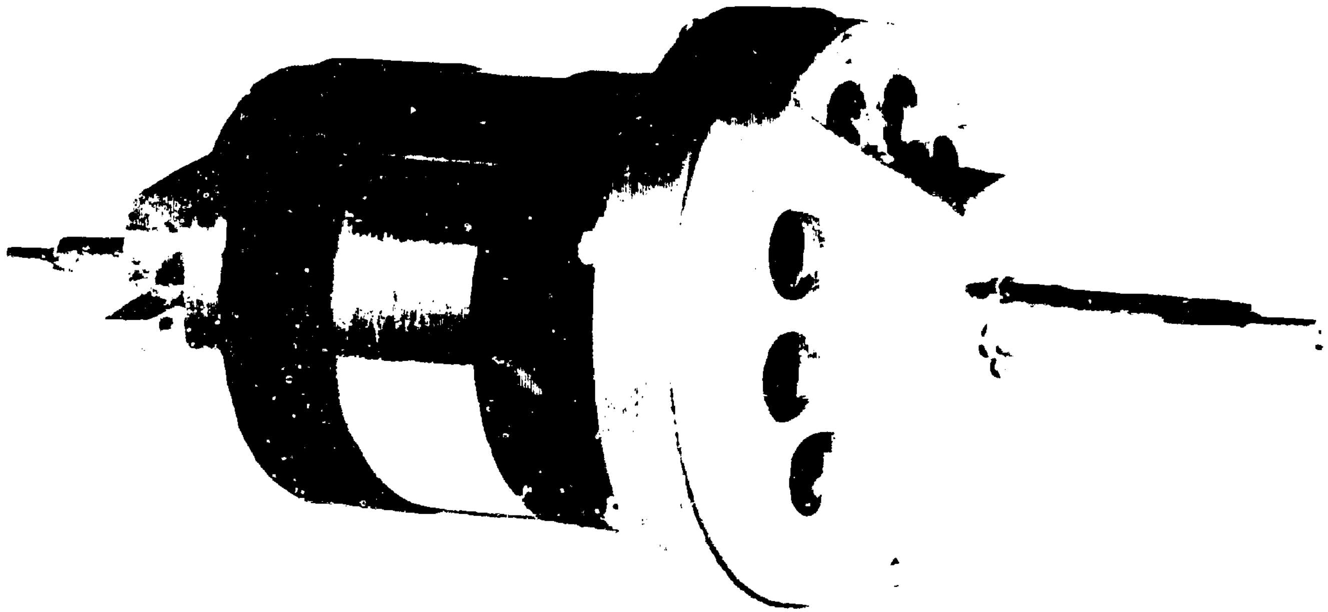


FIGURE 3

ALTERNATOR-DRIVE SUBASSEMBLY

manufacturer (United Shoe Machinery Corp).

The alternator-drive subassembly was placed in a machined aluminum housing composed of a square center section and two mating cylindrical endbells. Endbells are connected to the center section at flange interfaces by screw attachment.

Noise evaluation and generated performance data resulted in determination of an optimum alternator design and selection of noise damping materials to be used for drive sound suppression in the final configuration.

2.3 Development Model

2.3.1 Alternator and Output Circuit

Subsequent evaluation of experimental alternator design dictated the final stator winding configuration and indicates that a 6-pole rotor of approximately 6,000 RPM would fulfill the output requirements (Figure 2).

Alternator output is rectified to direct current through a full wave silicone diode bridge. Associated circuitry from the output of the rectifier to unit output terminals includes a combination voltmeter-ammeter controlled by an external switch selector for output monitoring and relay controlled reverse current protection of the meter. Selection of the meter was predicated by characteristics providing easy readability of output parameters supplemented

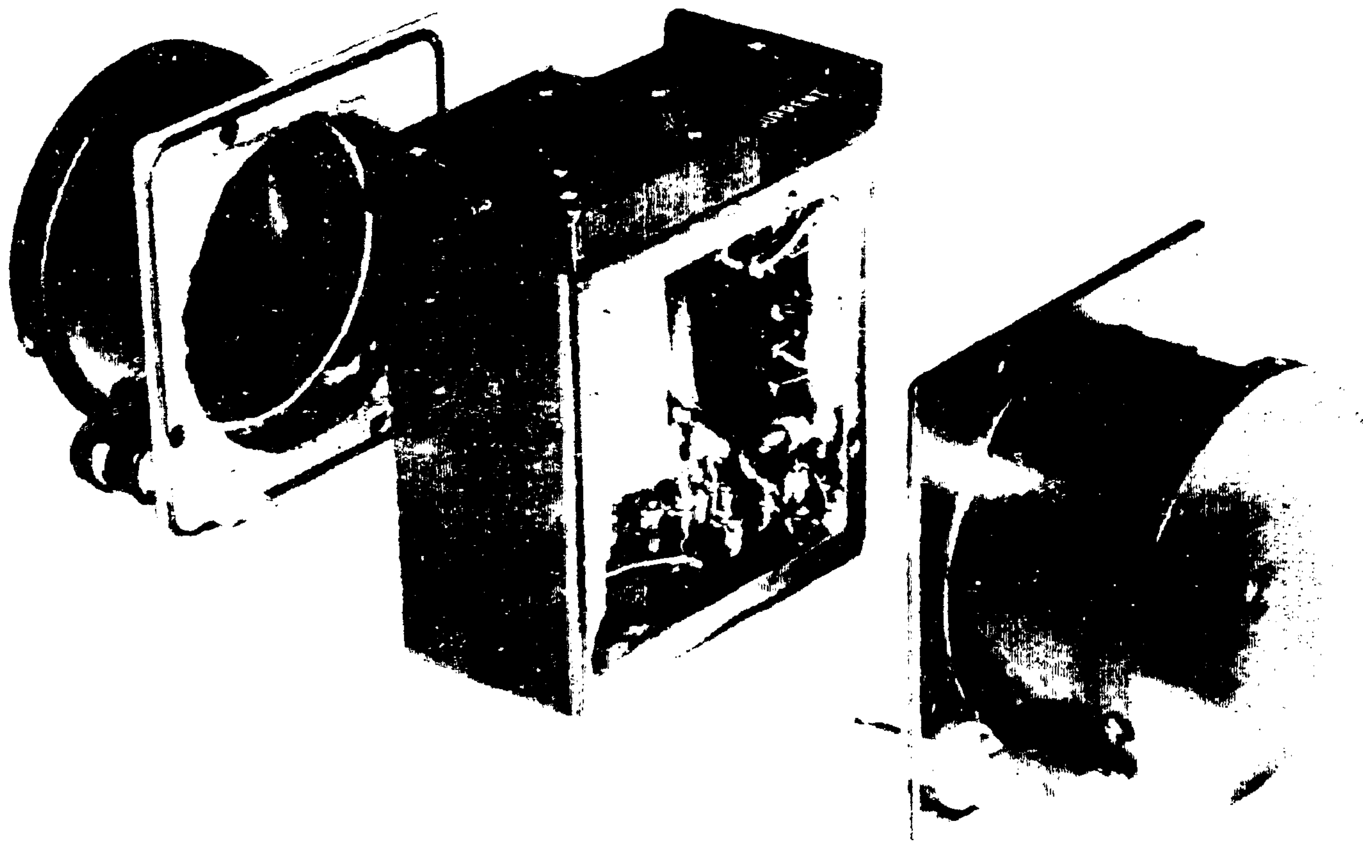


FIGURE 4
HOUSING

by scale color coding for simple identification of operating ranges and rugged construction for maintaining operation after rough unit handling.

Alternator-rectifier efficiency was attained at an optimum 75%.

2.3.2 Harmonic Drive

A size 20, 96-to-1 ratio harmonic drive was selected to provide necessary power for rotor rotation. Again, the long lead delivery necessitated in-house responsibility for lengthening the flex spline (Figure 2).

This higher ratio drive produced a greater acoustic noise output resulting in considerable additional experimentation involving sound absorption and housing dampening materials to determine a configuration that achieved the quietest operation.

Additional testing involved determination of causes contributing to low drive efficiency and modifications to resolve this problem. The harmonic drive could not achieve the necessary efficiency at rated speed and torque -- only allowing an overall efficiency in the range of 50%.

2.3.3 Housing (Figure 4)

A three-piece housing configuration provides

minimum volume identical to that of the experimental model and is formed of dip brazed aluminum alloy parts to achieve substantial weight reduction, economy of fabrication, and strength. The housing is fabricated for minimum size required to contain the alternator-drive subassembly and associated circuitry. The center housing internally mounts electrical components by use of threaded studs, and externally mounts the combination voltmeter-ammeter and its control switch for monitoring charging characteristics. Placement of the monitor meter, switch selector and output terminals includes considerations for facilitating operation, ease of observation, identification, and protection from adverse effects during handling.

2.3.4 Base

Development of the base mount for the generator evolved through two basic structures. The initial design was constructed of 6061-T6 aluminum alloy tubing and incorporated a battery clip and screw-type device for belt tightening during mounting. This configuration did not provide sufficient rigidity or mounting stability during generator operation. The battery clip was subsequently removed to reduce weight.

The final universally adaptable configuration consists essentially of a rigid tubular 6061-T6 brazed

aluminum base structure, mounting the generator at a forward vertical location, and an attached combination seat-knee pad. The base includes integral mounting jaws for gripping and which are spaced for mounting rigidity. Seat and belt attachment points are provided to allow the generator to be operated on the ground in a sitting or kneeling position, or when attached to random objects, preferably trees or posts. The base holding arrangement utilizes the nylon belt with attached tightening clamp assembly to secure the base in place.

Foamed-in-place plastic material was selected for installation inside the tubular structural members of the base to reduce acoustic noise by attenuating vibration induced by generator operation.

2.3.5 Crank Assembly

A folding crank assembly with friction reducing roller grip is connected to each end of the shaft protruding through openings provided in each end of the cylindrical housing sections.

When in the unfolded or operating position, the crank handles are 180° out of phase to provide a more balanced continuous cranking motion. A cranking radius of six inches provides sufficient leverage for input power in relation to arm motion required. This, combined with crank operating plane separation,

negates possible interference between the crank handle and proximate objects to which the total unit may be attached. Mounting hubs provide an interface between the crank and drive shaft by self-locking screw attachment. The hubs serve as pivot points for the cranks to maintain the required relative position with the drive shaft. Integral with each crank is a slotted jaw which captures the end of the drive shaft at a point providing flat locking surfaces when the handles are folded to the operating position. The handles fold 180° toward the center housing and are rotated against the base structure for storage when the generator is not in use. This provides protection for the handles and a more compact package during transport. The folded handles are cradled in position by the seat when it is latched in place, thereby forming a compact package for carrying or shipping.

2.4 Results

2.4.1 General

Operational tests were performed on the final complete generator unit design to insure compliance with overall specification requirements. Development criteria established for the G-63 generator were satisfied within the realm of state-of-the-art, in the design evolution. Following are some of the

major problem areas encountered.

2.4.2 Efficiency

The overall efficiency in the range of 50% is a direct function of the harmonic drive unit which provides a drive efficiency of about 67% at the nominal 60 RPM input speed. This efficiency level initially caused great concern because of the manufacturer's indication that the drive efficiency should have exceeded 80% at our rated requirements. Additional comprehensive efficiency tests conducted with standard drives and drives with flex splines modified in-house, such units run as both speed increaser and decreaser, verified the lower efficiency level. This was substantiated by efficiency curves provided by the manufacturer on a subsequent project quote. The flex splines modified in-house provided a two percentage point higher efficiency level than standard units. Performance data obtained from the finalized design units demonstrates that the overall unit efficiency increases as a function of operating time. The two units subjected to Life Test achieved an average 4.8% increase in efficiency. This increase is attributed to seating of seals and interface wear-in of the drive system components.

2.4.3 Acoustic Noise

Reducing the acoustic noise to an acceptable level was accomplished through extensive experi-

mentation and analysis. Radiated and transmitted noise required individual and combined approaches to selecting materials and configuration for the alternator-drive rubber suspension, structural damping of the housing and base and the introduction of sound absorption materials where possible. Initially, internal alignment between components was considered a factor. This is believed resolved by tightening tolerances and providing positive interfaces between mating components. Data obtained from unit operation just after assembly compared with units subjected to additional operation indicates that a further reduction in noise level is achieved as a function of the seating of mechanical components.

2.4.4 Weight

A foremost consideration in all design areas has been to achieve minimum weight while maintaining high reliability and economy of product. Nearly all component areas have had weight reduced to a minimum. Considerable contributors to excess weight are the housing damping materials required to decrease the acoustic level generated by the harmonic drive and weight of the harmonic drive circular spline and wave generator assembly as indicated by the following weight summary:

WEIGHT SUMMARY OF TYPICAL COMPONENTS

	Wt-Lbs.
Alternator-Drive Assembly Housing and Electrical Components	3.23
Base, Seat and Fittings	1.25
Handles w/Hubs	.38
Damping Material	.33
	5.19

WEIGHT SUMMARY OF HARMONIC DRIVE COMPONENTS

	Wt-Lbs.
Flexspline	.09
Wave Generator Bearing	.06
Wave Generator Hub	.25
Circular Spline	.19
	.59

2.5 CONCLUSIONS AND RECOMMENDATIONS

Subjecting the generator unit to qualification testing according to SCL 7828 revealed no degradation in operational performance.

The efficiency of the harmonic drive is about maximum for the present application. Nominal mechanical efficiency may be increased from the present 67% quoted by the manufacturer to 70.5% by utilizing an 80-to-1 drive ratio according to the manufacturer. This would result in trade-offs with the alternator design due to the speed change with slight increase in overall unit efficiency from a nominal value of 50%. More recent harmonic drive developments recommended by the manufacturer provide a weight reduction in the wave generator and circular spline which affects a 2-1/2 ounce decrease in drive weight.

Further reduction in the noise level may be realized by implementing a housing cast from magnesium alloy for inherent sound damping characteristics. Additional strength, heat transfer capability and interchangeability with existing components may be designed into the housing components as an added bonus. Possibly, little weight increase will be encountered because sound suppression material may be decreased or eliminated by damping capability of cast material.

2.6 RELIABILITY

circular spline cross section as recommended by the manufacturer should be considered toward reduction of overall weight of the complete unit. Additional improvements may be forthcoming in this area. The use of the harmonic drive in the G-63 generator allows a maximum utilization of alternator-drive components in a minimum space envelope to provide a more compact unit.

Final Design Improvements

Operation of the complete generator unit in the finalized design configuration revealed several component interface areas where improvements were incorporated to promote operational reliability and maintainability.

Flex Spline and Stator Mounting

The inherent flex spline wall thickness dictates that a reasonable amount of precaution be taken to prevent distortion during assembly and disassembly of the stator, stator mount, and flex spline. An initial procedure was to use the flex spline outside diameter as a holding surface but subsequent experience indicated this to be a marginal procedure if inexperienced personnel are performing the function. Flex spline and stator yoke were modified accordingly by adding clearance and spanner wrench sockets to the respective parts. This provided a more efficient holding mechanism for the stator yoke while the yoke mount was being tightened to secure flex spline, stator yoke, and yoke mount together as an integral assembly. A nylon insert was incorporated in the yoke mount thread area to act as a locking device preventing loosening of the yoke mount during normal and reverse operations of the unit. In addition, lock pins were installed at the flex spline-stator yoke interface to positively prevent rotation of the flex spline under maximum load conditions.

2.6.1 Use Reliability

Calculation of the predicted use reliability was performed according to the procedures outlined in Military Handbook 217, Reliability Stress and Failure Rate Data for Electronic Equipment. The procedure involved classification of parts or components according to category. Respective compiled average or severity rate functions and functions obtained from reliability stress calculations based upon part specifications and actual operating parameters, when summed, determined the predicted reliability expressed as Mean Time Between Failure. The calculated Mean Time Between Failure for the G-63 generator is 2903 hours. Accompanying data is included in the Appendix.

2.6.2 Maintainability

Incorporated in the overall generator design are features to facilitate ease of maintenance. This has been achieved by use of and placement of components for accessibility in the event that trouble shooting is required. The total unit may be disassembled and assembled with standard tools such as screw driver, pliers, and soldering iron, or improvised tools if necessary. Electrical component trouble shooting is facilitated after disassembly of the housing by clear access to all

internal electrical connections for test equipment readout.

2.6.3 Improvements

Areas of component up-dating included in the conclusions and recommendations could increase overall equipment reliability and increase rating of solid state electrical circuit components. Increased rating of these components may be achieved by reducing ambient component operating temperature with improved unit-housing transfer characteristics, thus providing increased current carrying or electrical power dissipating capacities. Additional reliability may be incorporated by reduced internal wiring achievable as a peripheral effect of the approach outlined in the following modular concept. Reduction of the internal electrical component mounting to a single module will decrease fabrication time and expense by elimination of certain mounting studs and wiring connections during final assembly, thereby contributing to greater economy and reducing logistics requirements from three components to a single component. On the other hand, this requires a trade-off with capability for single operating area component replacement.

HARMONIC DRIVE EFFICIENCY TEST-SPEED INCREASER

Harmonic Drive Configuration	Output Shaft Speed RPM	Input Shaft Torque In.-Lb.	Output Shaft Torque In.-Oz.	Efficiency %
Standard Flexspline, Modified Wave Generator	6750	47.7	3	37.8
		62.1	5	48.4
		79.0	7	52.9
		100.5	10	59.4
		114.0	12	63.1
Modified Flexspline, Standard Wave Generator	6000	55.0	4	44.1
		72.5	7	58.1
		92.5	10	65.0
Modified Flexspline, and Wave Generator	6750	51.4	3	35.9
		63.2	5	47.5
		77.2	7	54.6
		95.2	10	63.2
		110.3	12	65.4

Efficiency is determined as a ratio of power output to power input for 96 to 1 ratio.

Test data represent average of tests for each configuration listed. Tests performed in fixture providing for stationary circular spline and driven flexspline. Lubrication was 2 cc Type A Automatic Transmission Fluid. Modified flexspline defined as lengthened to G-63 design. Modified wave generator incorporates increased bearing clearance.

Table 1

TEST EQUIPMENT - SPEED INCREASER EFFICIENCY

0 to 100 In. - Lb.

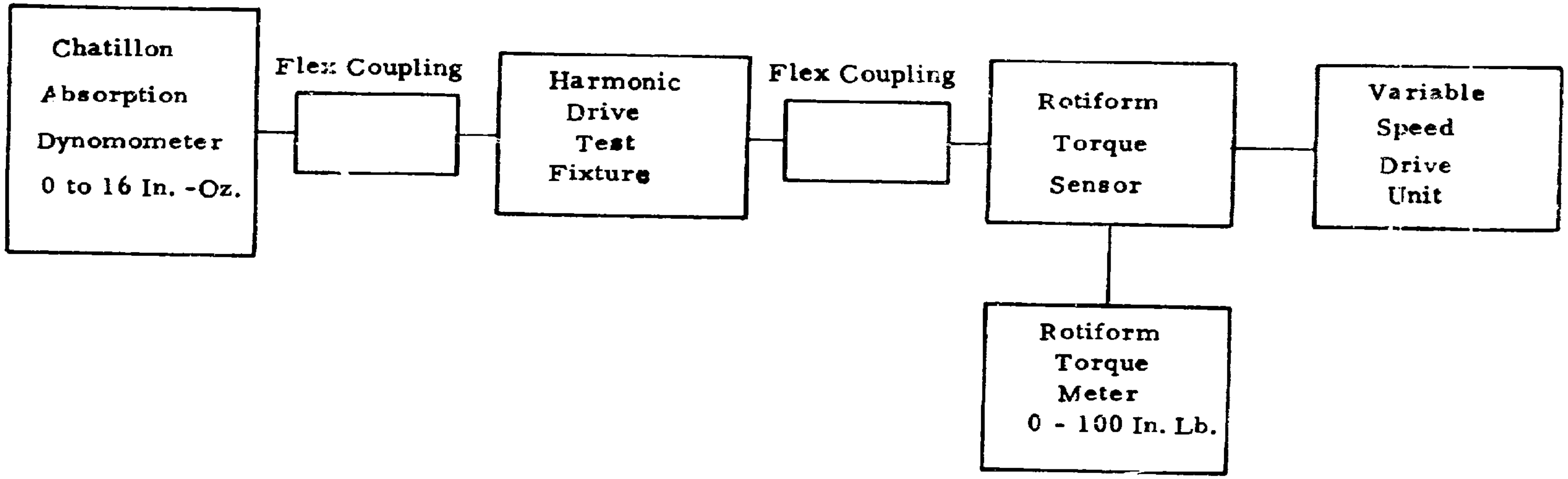


Figure 5

APPENDIX

Information contained in the Appendices describe in detail major development areas associated with the Generator, Direct Current, G-63 ( )/G.

TEST EQUIPMENT - SPEED INCREASER EFFICIENCY

0 to 120 In. - Lb.

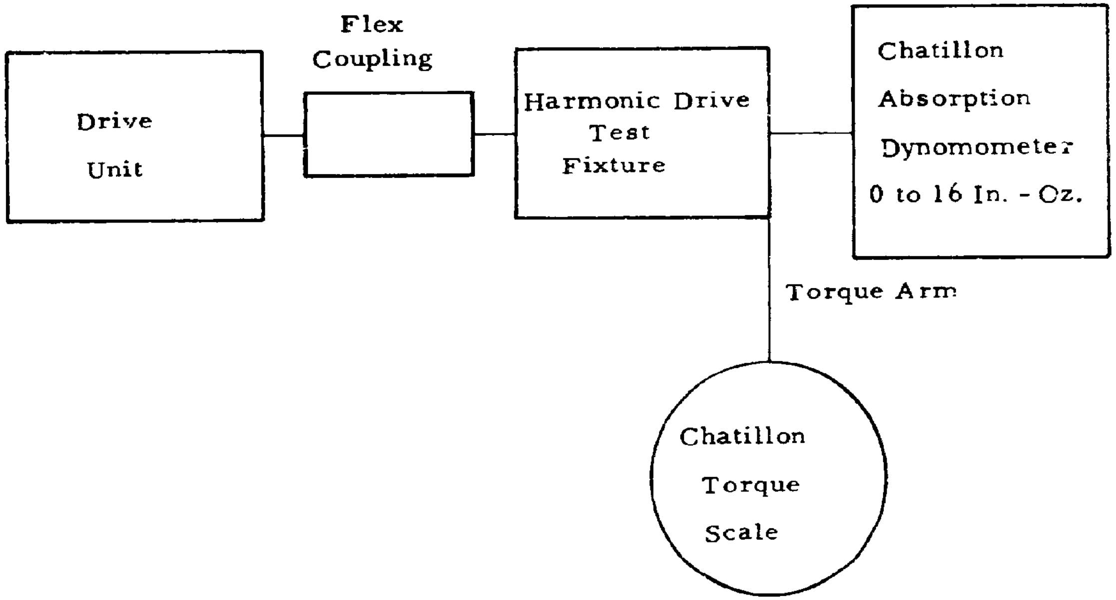


Figure 6

EFFICIENCY TEST - SPEED INCREASER

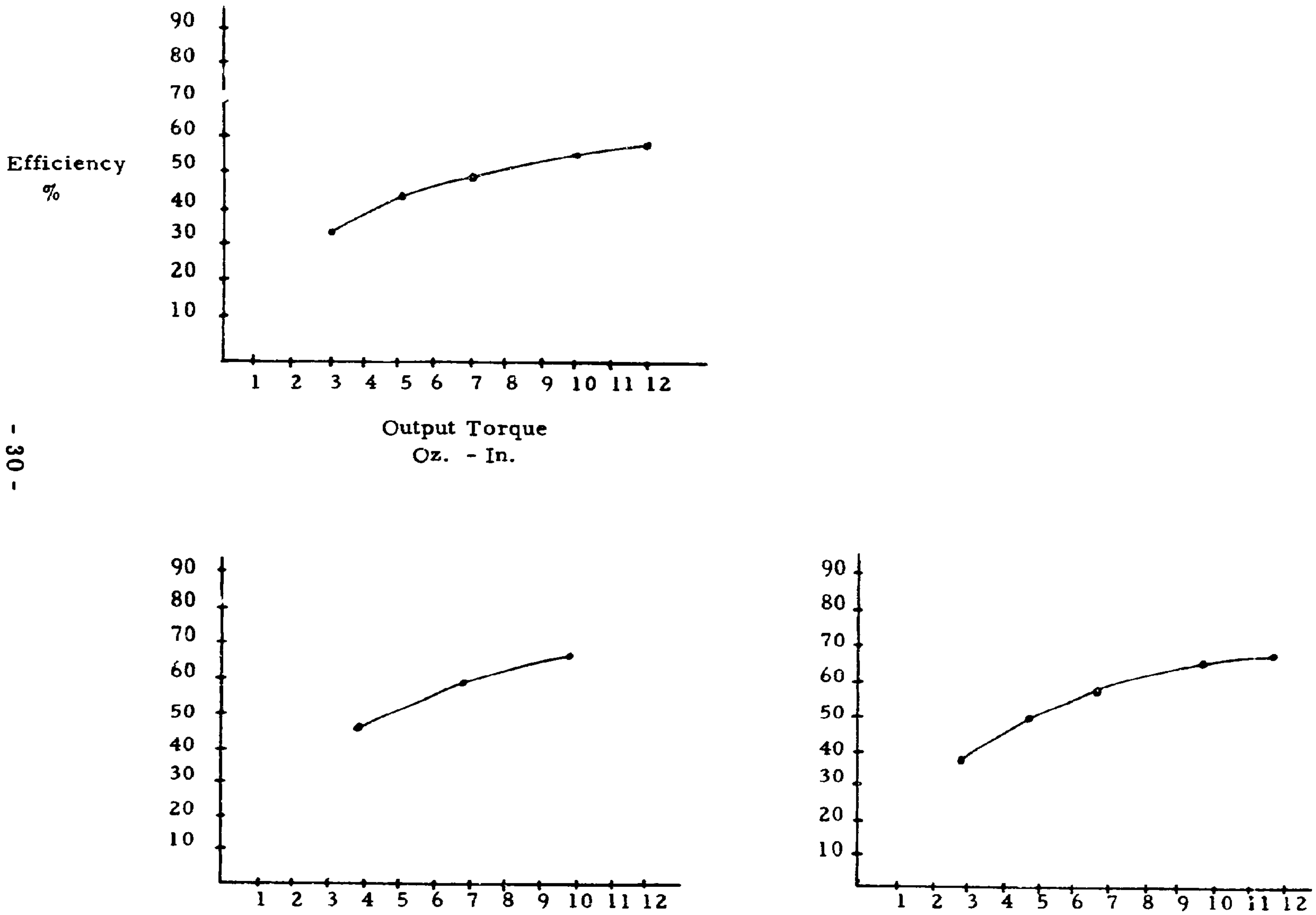


Table 2

In addition to the meter, the alternator and rectifier is protected against reverse connection of the battery by the 12 vdc relay. The relay coil is connected directly across the output terminals through a blocking diode CR3. If the battery should be reverse connected, it will energize the relay, whose contacts will open, and isolate the battery from the generator.

Under normal operation, the charging rate can be determined by placing the meter switch SW1 in the "current" position. This puts the meter coil in parallel with the meter shunt connected across terminals 1-2 in the meter circuit. Read-out of the charging rate is displayed on the inner scale of the meter which is divided into three different colored graduations, white, green, and red, the limits of which indicate a current flow of 1, 2, and 3 amps dc respectively. The charging rate is adjusted to the desired value by varying the cranking speed.

Electrical Connections

Maintainability was increased by replacing the solder-type connection of electrical leads to generator output terminals with a lug-type connector secured with nut and lock-washer.

HARMONIC DRIVE EFFICIENCY TEST

SPEED DECREASER

Harmonic Drive Configuration	Input Shaft Speed - RPM	Input Shaft Torque In. -Lb.	Output Shaft Torque In. -Lb.	Efficiency %
Standard Components	1800	1.25	46.25	38.5
		2.50	139.00	57.9
		3.50	231.00	68.8
		4.65	324.00	72.7
Modified Flexspline		0.95	46.25	50.7
		2.25	139.00	64.3
		3.25	231.00	74.1
		4.30	324.00	78.3

Efficiency is determined as a ratio of power output to power input. Test data represent average of tests for each configuration listed. Tests performed in fixture providing for stationary circular spline and driven wave generator. Lubrication was 2 cc Type A Automatic Transmission Fluid.

Table 3

HARMONIC DRIVE EFFICIENCY TEST

SPEED DECREASER

Harmonic Drive Configuration	Input Shaft Speed - RPM	Input Shaft Torque In. -Lb.	Output Shaft Torque In. -Lb.	Efficiency %
Standard Components	1800	1.25	46.25	38.5
		2.50	139.00	57.9
		3.50	231.00	68.8
		4.65	324.00	72.7
Modified Flexspline		0.95	46.25	50.7
		2.25	139.00	64.3
		3.25	231.00	74.1
		4.30	324.00	78.3

Efficiency is determined as a ratio of power output to power input. Test data represent average of tests for each configuration listed. Tests performed in fixture providing for stationary circular spline and driven wave generator. Lubrication was 2 cc Type A Automatic Transmission Fluid.

Table 3

TEST EQUIPMENT - SPEED DECREASER EFFICIENCY

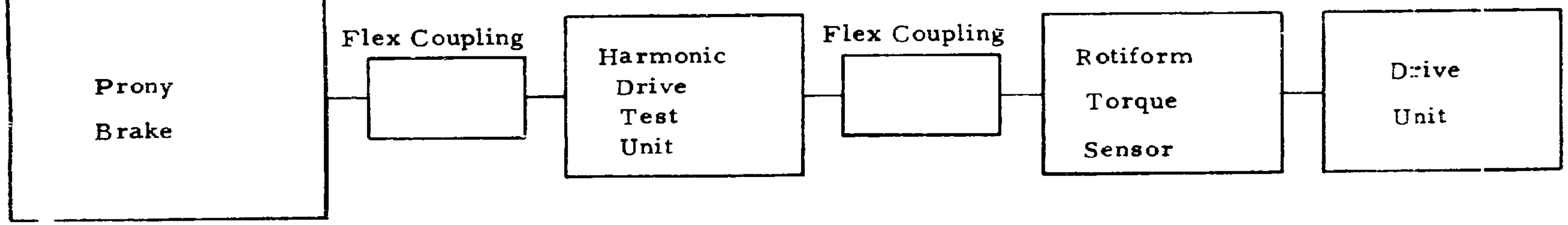
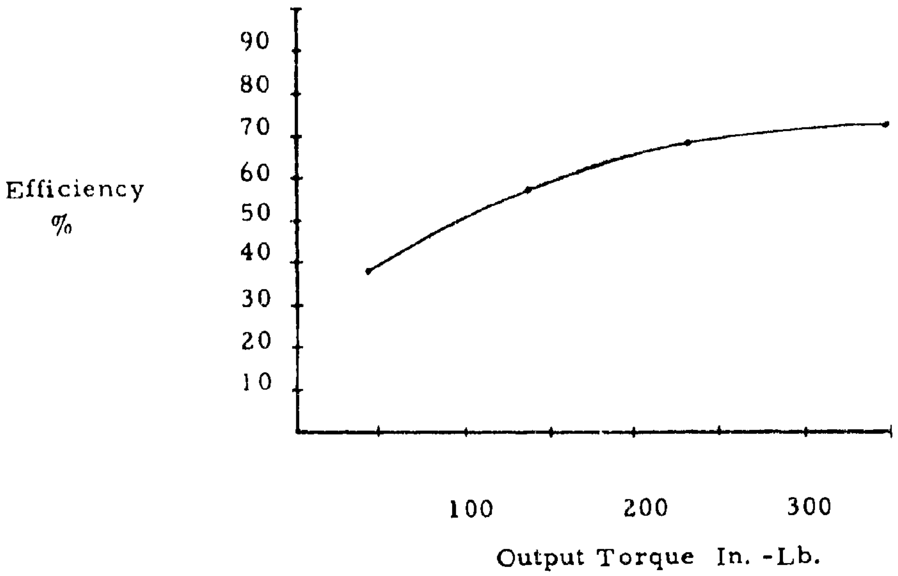
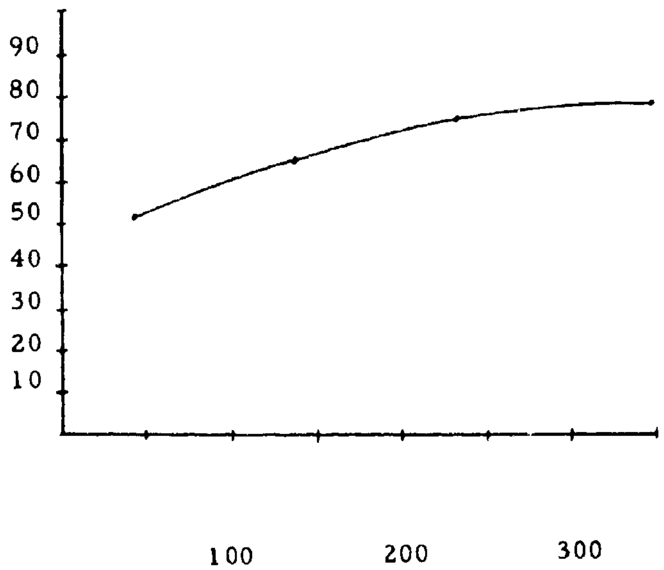


Figure 7

Table 4

Efficiency Test - Speed Decreaser





APPENDIX 2

MECHANICAL DRIVE

The mechanical power transmission system providing alternator input is the United Shoe Machinery Corporation harmonic drive, consisting of a flex spline, circular spline, and wave generator.

Considerations in adopting this type of drive to the experimental model generator unit were: efficiency, drive ratio, size, mounting, lubrication, modifications required, ability to transmit power, and generated acoustic noise.

Configuration

Preliminary design and alternator determination resulted in the basic mounting geometry dictated by the drive system. The drive system, devised to allow minimum volume for components required, resulted in a main drive shaft for harmonic drive circular spline input power about which rotates a counter shaft mounting to the alternator rotor.

Appropriate relationship is achieved by complimentary precision ball bearing supports.

Design

Determination of the initial rotor configuration by design and comprehensive testing established the length required for the flex spline. The length required was greater than available standard components and due to long lead delivery, in-house flex spline modification was

* TYPICAL G-63 GENERATOR PERFORMANCE TEST DATA

	Output Voltage VDC	Output Current Amperes	Input Shaft Speed - RPM	Input Shaft Torque - In. Lb.	Efficiency %
1.	12.6	1.65	50	76	45.62
	12.3	1.63	50	73	46.36
	12.6	1.65	50	80	43.87
	15.1	1.96	60	85	48.99
	14.8	1.93	60	89	45.14
	15.1	1.92	60	91	44.81
	20.3	2.60	80	104	53.54
	19.6	2.50	80	106	48.77
	20.4	2.62	80	110	51.26
2.	14.8	1.80	58	84	46.20
	14.9	1.93	60	74	54.65

$$\text{Efficiency} = \frac{84.5\ W}{F\ N}$$

where

W = EI Watts Output
N = Input Shaft RPM
F = In. Lbs. Torque

1. Indicates unit performance as assembled.

2. Indicates unit performance after operation.

* Performance data obtained as a function of cranking speed.

Table 5

* TYPICAL G-63 GENERATOR PERFORMANCE TEST DATA

	Output Voltage VDC	Output Current Amperes	Input Shaft Speed - RPM	Input Shaft Torque - In. Lb.	Efficiency %
1.	12.6	1.65	50	76	45.62
	12.3	1.63	50	73	46.36
	12.6	1.65	50	80	43.87
	15.1	1.96	60	85	48.99
	14.8	1.93	60	89	45.14
	15.1	1.92	60	91	44.81
	20.3	2.60	80	104	53.54
	19.6	2.50	80	106	48.77
	20.4	2.62	80	110	51.26
2.	14.8	1.80	58	84	46.20
	14.9	1.93	60	74	54.65

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where

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Table 5

APPENDIX 3

ACOUSTIC NOISE

Experimental Unit

Initial efforts to suppress acoustic noise were directed toward determining materials that would attenuate housing vibration and absorb noise radiating from the harmonic drive. Evaluation was started on the experimental model with machined aluminum case and 80-to-1 harmonic drive ratio. Foamed-in-place plastic, undercoating, various rubber compositions, and available sheet sound deadening materials were alternately and in combination placed in the center and endbell sections of the housing.

Initial noise levels measured without damping material installed were 72 db when measured according to SCL 7828.

A plastic coating was applied to the circular spline teeth. This reduced the noise level 1 db but adhesion could not be maintained in areas of high contact pressure. With undercoating material applied to the inside of the housing, the noise level was reduced to 66 db.

Several lubricants were evaluated as a function of reduced noise output. The lubricants ranged from light machine oil and molybdenum disulfide additives to silicone grease. By providing light oil lubrication to the wave generator bearing, lubrication load is kept at a minimum. Light oil in copious quantity on circular spline teeth reduced the noise level somewhat but could not be considered because of poor retention quality. Use of silicone grease on circular spline teeth proved superior to gear grease and exhibited good retention as well as reducing the noise level.

The noise level was eventually reduced to 57 db by providing a 40 durometer neoprene suspension between the 2 crank drive shaft bearings and the housing, applying a layer of undercoating material to inner housing walls and filling internal space between flex spline and housing, where possible, with polyurethane foam sheet for sound absorption.

Installation of epoxy foam increased the sound level and was rejected as was the undercoating material due to incompatibility with required maximum operating temperature and lubricants.

The information thus gained was then used in the development of the final housing configuration with the 96-to-1 ratio harmonic drive and 6-pole alternator.

G-63 Generator

The noise level generated by the 96-to-1 ratio drive was higher than that encountered with the experimental unit and required further investigation of procedure to reduce noise output. Noise output varied with operating load, usually showing a 1 to 3 db increase over no load conditions.

Application of GP-1 and Epoxy 10 damping compounds manufactured by the Soundcoat Company proved increasingly more effective in reducing the noise level over the original undercoating material when applied to the inside surface of the dip brazed aluminum housing. In addition, it is not as susceptible to damage due to handling and is impervious to lubricants.

Both compounds are of plastic base material with a lightweight filler and heat cured after application. GP-1 is premixed by the manufacturer

The noise level was eventually reduced to 57 db by providing a 40 durometer neoprene suspension between the 2 crank drive shaft bearings and the housing, applying a layer of undercoating material to inner housing walls and filling internal space between flex spline and housing, where possible, with polyurethane foam sheet for sound absorption.

Installation of epoxy foam increased the sound level and was rejected as was the undercoating material due to incompatibility with required maximum operating temperature and lubricants.

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Application of GP-1 and Epoxy 10 damping compounds manufactured by the Soundcoat Company proved increasingly more effective in reducing the noise level over the original undercoating material when applied to the inside surface of the dip brazed aluminum housing. In addition, it is not as susceptible to damage due to handling and is impervious to lubricants.

Both compounds are of plastic base material with a lightweight filler and heat cured after application. GP-1 is premixed by the manufacturer

and Epoxy 10 is mixed prior to application. Each type has different sound attenuating and strength characteristics. GP-1 is lighter weight and provides greater noise suppression but lacks the strength of Epoxy 10. They are applied in a configuration utilizing the best characteristics of each and provide reduction of noise level in the range of 10 db. Rubber suspension was provided between the circular spline and drive yoke with little effect. Combinations of drive yoke and flex spline fiberglass housings internal to the primary housing produced slight noise reduction due to their resonant ability.

Efforts were then directed toward investigation of the crank drive shaft bearing suspension system. Use of a higher spring constant suspension system on other programs indicated that a similar application might significantly reduce the noise level by providing greater vibration isolation in the G-63 unit.

The bearings were supported in 3/8" width neoprene of varying durometer to provide increased isolation between the alternator drive subassembly and housing. Additional noise measurements indicated a 1 db decrease in noise level. This type suspension accelerated a weight increase.

Further analysis was then initiated on the standard suspension system where the square bearing supports are provided with molded neoprene mounts in the housing endbells for vibration isolation. When the generator unit was in operation, the cranking torque was transmitted to the bearing mount supporting the stator. The torque concentration at this point caused the bearing support to rotate, cut into the neoprene suspension material and cause contact with the housing. Installation of a pair of torque arms to the bearing mount reduced the contact pressure. The torque arms are suspended in neoprene in their containment slots to assist in carrying the torque load. This configuration produced a noise

level reduction equivalent or better than the heavier suspension. Utilizing a frequency analyzer at the output of the sound level meter, adverse frequencies contributing to maximum noise output were determined in the range of 200 to 600 cycles per second. This range includes the approximate functions of flex spline oscillation (200 cps) and tooth mesh (400 cps). The major harmonic drive noise contributor appears to be a function of flex spline oscillation caused by wave generator rotation and initiated by circular spline actuation, thus causing a loudspeaker effect. Additional testing with thin rubber coatings applied to the internal and external surfaces of the flex spline failed to produce any observable reduction in noise output.

Subsequently in the program a flex spline resonance damping system composed of a material with greater spring constant and environmental compatibility was applied with pre-tension at 2 locations on the flex spline. This application resulted in a noise reduction up to 5 db while cranking the alternator-drive subassembly in an open fixture. The flex spline with this type damping produced no observable increase in input torque.

An additional contributor to noise output was the base mounting structure. Plastic foam damping compound was injected into the structural tubing members and allowed to expand into place. The structural rigidity was thereby increased with slight weight increase. A 1 db reduction in the noise level was attained.

GP-2 sound damping sheet consisting of regulated density polyurethane foam with vibration damping compound backing was utilized in varying quantities with noise reduction up tp 2 db depending upon the amount used. Unfortunately this type of material does not lend itself well to mass production installation. It is installed where possible in endbell

areas remote to operating components for sound absorption.

Since the harmonic drive in this application is operating at approximately 30% of rated torque capacity, the tooth contact width between the circular and flex spline was proportionally reduced. The resulting noise level decrease was approximately 2 db.

Incorporation of the shaft seal system contributes to increasing the stiffness of the suspension system and appears to effectively damp the crank drive shaft. This results in 1 db or better decrease in the noise level.

Noise measurements observed on the final development model indicated a noise level of 55 db. All described measurements were taken in accordance with the procedure required in SCL 7828. The developed configuration incorporates the GP-1, Epoxy 10 damped housing, moulded neoprene suspension of crank drive shaft bearing supports supplemented with torque arms, reduced gear tooth contact, and damped base structure.

CONFIGURATION DEVELOPMENT FOR ACOUSTIC NOISE REDUCTION

Configuration	Meter Weighting Noise Level A	Meter Weighting Noise Level B	Location	Remarks
Experimental Unit Unmodified	72	72	Field - Wooded area	All readings with generator operated on tubular tripod mount with 7.5 ohm output load.
Styrofoam inside walls of housing. Teflon circular spline and stator isolators.	70	70		
Neoprene bearing suspension. End bell gaskets.	67	70		
Remove Styrofoam. Undercoat inside housing. Plastic coat circular spline teeth.	65	66		
Flexspline wrapped w/rubber felt.	61	63		
Undercoating, damping sheet Silicone grease lube.	58	60		
Polyurethane foam in available housing space.	56	57		

Table 6

CONFIGURATION DEVELOPMENT FOR ACOUSTIC NOISE REDUCTION

Configuration	Meter Weighting Noise Level A	B	Location	Remarks
G-63 Generator			Field - Open area	Pole mount
Unmodified	74	75		
GP-1, Epoxy 10 damping compounds on interior housing walls, Moulded Neoprene bearing suspension.	65	65		
Coated Flexspline.	65	65		
Heavy Neoprene suspension. w/stator support. Torque arms.	63	62		Pole mount, no load.
	63	64		Pole mount, 7.5 ohm load.
	61	62		On ground, no load.
	62	64		On ground, 7.5 ohm load.
Reduced gear tooth contact.	61	61		Pole mount, 7.5 ohm load.
Moulded Neoprene suspension w/stator support torque arms.	62	61.5	Engineering Lab	Bench mount, 7.5 ohm load.
Flexspline resonance damping. Stiffened base structure. Shaft seals installed.	55.5	55	Field - Wooded area	Ground mounting, BB-486/U battery load.

Table 7

APPENDIX 4

MATERIAL APPLICATIONS

Constant consideration has been given throughout the G-63 generator development toward utilization of materials, components, and processes that contribute to overall weight reduction and processing efficiency without reducing performance and handling capabilities.

Incorporating tubular and sheet metal aluminum alloy parts jointed by the dip brazing process for the base and housing components resulted in minimum weight with good strength characteristics. The joining process can be an economy factor for higher volume production consideration. One drawback to this type of construction is the limited vibration damping ability which requires the supplementary use of damping compounds. Multiple functions have been incorporated in regard to placement of components, such as meter, switch, output terminals and mounting of major subassemblies, so that protection and operability are afforded with minimum increase of material.

Corrosion resistant materials or standard parts and fittings processed for corrosion resistance have been incorporated where practical in the design.

APPENDIX 5

TABLE 8

COMPONENTS SUBJECT TO RELIABILITY ANALYSIS

Nomenclature	Manufacturing Information
1. Relay, DPDT 2 ampere rating, 6-volt, hermetically sealed.	Leach Corp., Relay Division Los Angeles, California P/N E-J2C - No Mil Spec. Equivalent.
2. Relay, DPDT 2 ampere rating, 12-volt, hermetically sealed.	Leach Corp. Relay Division Los Angeles, California P/N E-J2B - No Mil Spec. Equivalent.
3. Diode Bridge, 3-phase, 800-volt, PIV, 1 ampere	Diodes, Inc. Chatsworth, California P/N 5231 - No Mil Spec. Equivalent.
4. Diode	Motorola IN 4004
5 Switch, toggle-miniature 2-pole, DT, On-None-On positions.	MS 24656-231
6. Capacitor, Tantallic wet slug, 10-volt, 250 uf	G2F401 GE MIL-C-3965
7. Meter, sealed and ruggedized 10-20 VDC scale, 0 to 3 ampere, with shunt.	Parker Instrument Corp. Stamford, Connecticut R-15 series MIL-M- 10304 except dielectric strength of 500 VDC

Nomenclature	Manufacturing Information
8. Alternator, 3-phase, 6-pole.	Varo Inc. Santa Barbara, California
9. Harmonic Drive size 20, 96-to-1 ratio	United Shoe Machinery Corp. Beverly, Mass. Model HDUC 20-96-2
10. Bind post	Hugh H. Eby Company WB-8-CHAI
11. Electrical hardware	
12. Mechanical hardware	

Table 9

G-63 GENERATOR

Inherent Equipment Reliability

Part Type	Quantity Used	Failure Rate	Failures Per 10^6 Hours
Relay, EJ2C	1	293.0	293.0
Relay, EJ2B	1	26.8	26.8
Switch	1	6.8	6.8
Capacitor	1	0.6	0.6
Diode bridge	1	5.7	5.7
Diode	1	0.17	0.17
Diode	1	0.12	0.12
Meter	1	0.91	0.91
Alternator	1	5.84	5.84
Connector	2	0.09	0.18
Hardware, electrical			
terminals	28	0.033	0.924
Hardware, mechanical			
harmonic drive	1	0.092	0.092
bearings	5	0.092	0.46
handles	2	0.092	0.184
retaining rings	4	0.092	0.368
latch	1	0.092	0.092
vibration mounts	2	0.092	0.184
seals	14	0.092	1.288
couplings	2	0.092	0.184
switch slide	1	0.092	0.092
housing	3	0.092	0.276
spring	2	0.092	0.184
		SUMMATION	344.448

Mean Time Between Failure (MTBF) $= \frac{10^6}{344.448} = 2903$ Hours

APPENDIX 6

METALLURGICAL REPORT

MATERIALS TESTING LABORATORIES
DIVISION OF MAGNAFLUX CORPORATION
6800 EAST WASHINGTON BOULEVARD
LOS ANGELES 22, CALIFORNIA
TELEPHONE 685-6001

TO: VARO INC. - ELECTROKINETICS DIV.
402 E. Gutierrez St.
Santa Barbara, California
Attn.: Mr. Jim McKee

LABORATORY NO. 21912-5-1

DATE May 4, 1966

MATERIAL 321 Stainless Steel
Harmonic Drive Flexspline

SPECIFICATION

YOUR P.O. NO. 3495

METALLURGICAL REPORT

INTRODUCTION

One broken flexspline was submitted for investigation of the cause of a crack. This crack was observed after 35 hours at a duty cycle of 5 minutes on and 1 minute off. The teeth see a torque of approximately 50 inch-pounds maximum, simultaneously on opposite sides of the part, at a temperature of approximately 160°F. The part is smaller than the mating female spline, with the result that the male spline is flexing into a continually changing elliptical shape. Thus, the tooth section is also loaded in a cyclic reversed bending mode.

The part is made by silver brazing two sections together while the tooth portion is immersed in water to within 1/2 inch of the joint. The tooth portion is part of a commercially available item and this portion only is nickel plated on the inside surface. The outside surface of the splined area was shot-peened.

VISUAL EXAMINATION

The crack appeared to start in the spline area and extended along one root into the smooth area, terminating in a nearly circumferential direction. Cracking progressed without distortion or local deformation except near the terminating point. There was no evidence of the existence of cracks other than the primary one. It was noted that the spline teeth were not distorted or brinelled.

The metal was found to be very ductile in a static bend test. There was no significant cracking in a typical tooth root after bending double at about a 1-T radius. The nickel plating was cracked by this procedure but it did not give any indication of a lack of adhesion.

RESPECTFULLY SUBMITTED

C. Howard Craft
MATERIALS TESTING LABORATORIES
Metallurgy Department

MATERIALS TESTING LABORATORIES
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6800 EAST WASHINGTON BOULEVARD
LOS ANGELES 22, CALIFORNIA
TELEPHONE 685-6001

TO: VARO INC. - ELECTROKINETICS DIV.

LABORATORY NO. 21912-5-1

DATE

MATERIAL

SPECIFICATION

Page 2

YOUR P.O. NO.

MICROSCOPIC EXAMINATION

The basic microstructure in the cracked area was equiaxed austenite with no evidence of grain boundary precipitation. Cracking was transgranular, bearing no apparent relation to the microstructure. The nickel plating had the following characteristics:

Thickness	0.0013 inch
Hardness (Knoop 100 grams)	445 (Equivalent to 43.5 R"c")

CHEMICAL ANALYSIS

	Open (Splined) End	Closed End
Carbon, %	0.07	0.06
Manganese, %	1.78	1.86
Silicon, %	0.57	0.64
Phosphorus, %	0.010	0.010
Sulfur, %	0.005	0.002
Chromium, %	17.54	17.51
Nickel, %	12.52 *	10.40
Molybdenum, %	0.17	0.19
Titanium, %	0.43	0.34
Copper, %	0.13	0.16

RESPECTFULLY SUBMITTED

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Metallurgy Department

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LABORATORY NO. 21912-5-1

DATE

MATERIAL

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*This value for nickel is probably high due to the presence of residual amounts of nickel plate, which was difficult to remove prior to the analysis.

The results of the chemical analysis show conformance (except *) to the requirements of AISI 321.

A semi-quantitative analysis for phosphorus in the nickel plate indicated that the amount present was in excess of 5%.

REMARKS

The following specific conclusions result from the listed observations and tests:

1. The steels have the required chemical composition and the microstructure in the cracked area has not been adversely affected by the processing.

2. The internal coating is, in fact, electroless nickel plating. Its hardness and brittleness indicate that any heating subsequent to plating has been at a low temperature, that is, less than 500°F.

Failure of the submitted part is believed to have resulted from progressive cracking under loads which were primarily flexural. That the torque loads were not excessive is indicated by the lack of tooth deformation. It is clear that a fracture caused by tooth loads would have been accompanied by severe tooth deformation.

The fact that the nickel plate was somewhat brittle may have contributed to failure, but the absence of secondary cracks in the plating tend to show that this factor was not critical. It is believed that the contribution from this source could not have been in excess of a 20% drop in fatigue life.

RESPECTFULLY SUBMITTED

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VARO INC. - ELECTROKINETICS DIV.

LABORATORY NO. 21912-5-1

DATE

MATERIAL

SPECIFICATION

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YOUR P.O. NO.

The general effect of a plating on fatigue life is dependent upon the level of tensile stress in the plate. The stress pattern is a function of the bath conditions and subsequent stress relief. As-plated electroless nickel is relatively soft and brittle. Heating to 750°F. for one hour increases the hardness as high as 900 Knoop. In order to improve the ductility and lower the internal stress, it is necessary to heat to about 950°F., when the hardness will be somewhat higher than the as-plated hardness.

RESPECTFULLY SUBMITTED

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MATERIALS TESTING LABORATORIES
Metallurgy Department

Unclassified

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DOCUMENT CONTROL DATA - R&D

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Santa Barbara
California

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Fort Monmouth, N.J. ATTN: AMSEL-KL-PF

13. ABSTRACT

Generator, Direct Current, G-63( )/G developed ~~under this Contract~~ encompasses the requirements of USAECOM Technical Requirement SCL 7828.

Major component or subassembly areas involved with unit development may be classified as: Alternator and associated circuitry, mechanical drive, housing, and base assembly.

Electrical subsystem development included alternator optimization, rectifier selection, and design of protection and electrical output monitoring circuitry.

Mechanical drive development involved matching the harmonic drive to alternator requirements and additional testing required to isolate and rectify problems of low drive efficiency and high acoustic noise levels generated.

The housing was developed for minimum size and weight for containment of the alternator-drive subassembly and maximum acoustic noise suppression.

The mounting base assembly developed includes consideration for universal functioning and prime factors of weight, strength, and attachment.

Techniques were considered and implemented throughout the project to promote economical use of parts and fabrication processes. Use of standard parts and components where possible and joining major subassemblies such as housing and base components with the dip brazing process have been incorporated toward an economy which may become even more significant in mass production considerations.

Overall unit considerations resulted in an effort to integrate individual subsystem attributes into an economical unit incorporating factors contributing to operator efficiency for total operation and observation as encountered under field conditions. Post qualification analysis indicates that possible improvements may be merited in the areas of housing, electronics packaging, and internal component mounting to contribute to a more economical, lighter weight design.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Harmonic Drive						
Acoustic Noise						
Battery Charging						
Speed Increaser						

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